

Eric McDougall

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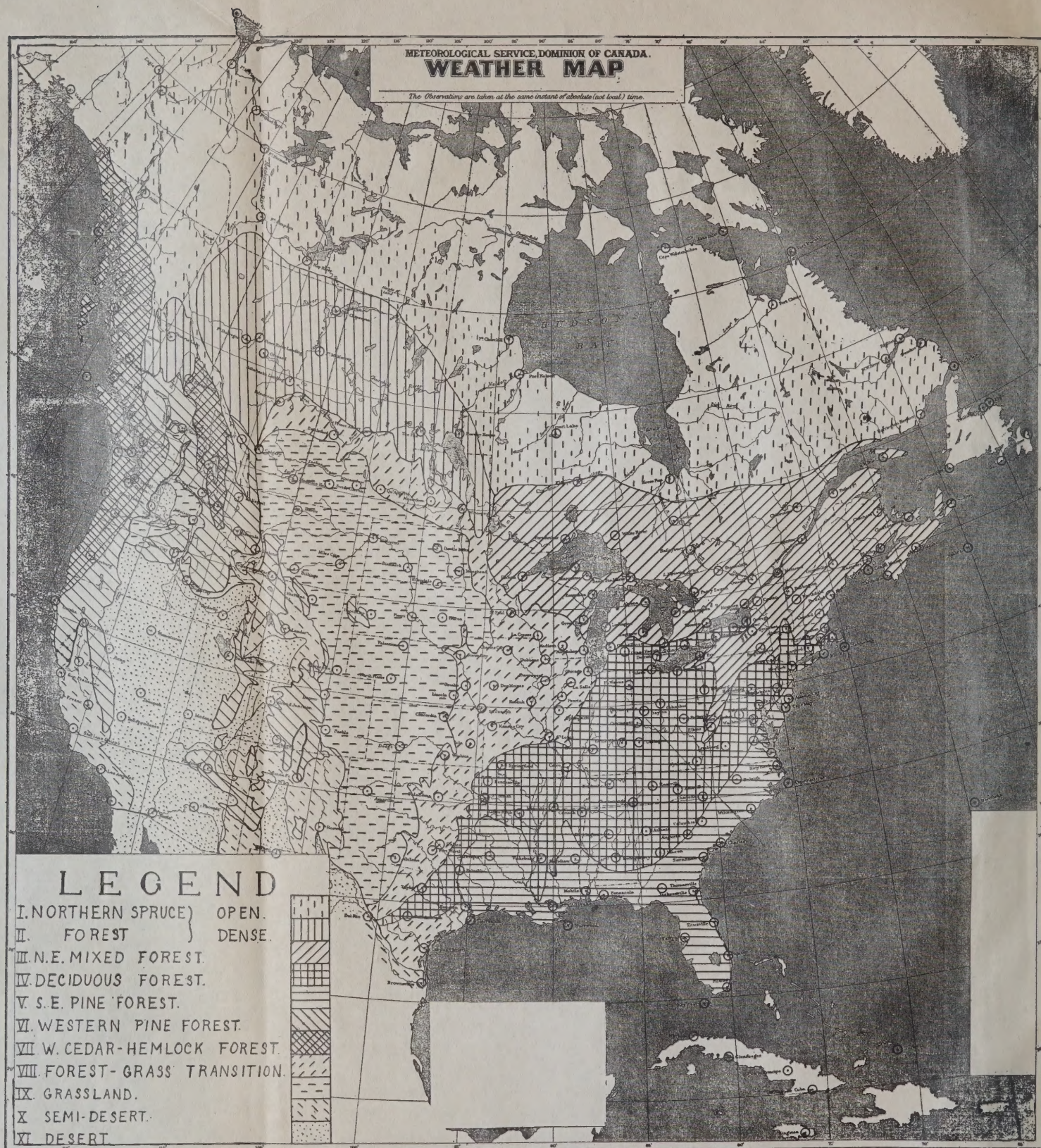


FIG. 1. Vegetation map of Canada and the United States, based on Shreve, on the Natural Resource Intelligence Service of Canada, and on Shantz and Zon.



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THE MOISTURE BELTS OF NORTH AMERICA

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Temperature and moisture are regarded as the chief climatic factors affecting the lives and distribution of terrestrial organisms, since a species can not long occupy a site too cold, too hot, too dry or too wet for its specific requirements. In the case of plants, it has long been recognized that the vegetative organs of different species were adapted to various conditions of water-supply; and also that the occurrence of the larger plant formations was mainly determined by the moisture factor in climate. In school geographies it is commonly stated that desert regions are those with less than ten inches of annual precipitation, that twenty inches annually is required to support forests.

If we wish to improve upon these rough approximations to truth, it seems obvious that outgo as well as income should be considered. The rain that falls is removed in part by surface flow and by seepage (conditions governed by edaphic factors, to which only incidental reference will be made), but mainly by the climatic factor of evaporation. Unfortunately, climatologists have not found a satisfactory method of measuring this important factor. Atmometer and evaporimeter measurements differ widely among themselves, depending on the type of instrument used. The floating pan evaporimeter may tell us something of the evaporation from free water surfaces; but the more complex problems of evaporation from soil and vegetation are still unsolved. Owing to the paucity of comparable evaporation measurements, Livingston and Shreve ('21), in their comprehensive endeavor to correlate vegetation and climate, had at their disposal only a single year's observations from a limited number of stations. Under the circumstances, it is not surprising that none of their "Moisture Maps" fitted the distribution of vegetation much better than the time-honored map of annual precipitation.

Where precipitation is scanty, it may be wholly removed by evaporation, leaving no surplus to appear as run-off. On this account the dry regions of the earth have a characteristic physiognomy. They contain no streams, save those that enter them from wetter regions; and these streams, unless large

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enough to make their way to the sea, end in saline lakes or sink into the desert sand. It is possible to map the dry regions on the basis of this characteristic of the absence of stream flow. This was done by Köppen ('20), who, assuming that evaporation was a function of the temperature, also worked out the relation of precipitation to temperature along the edges of the regions where

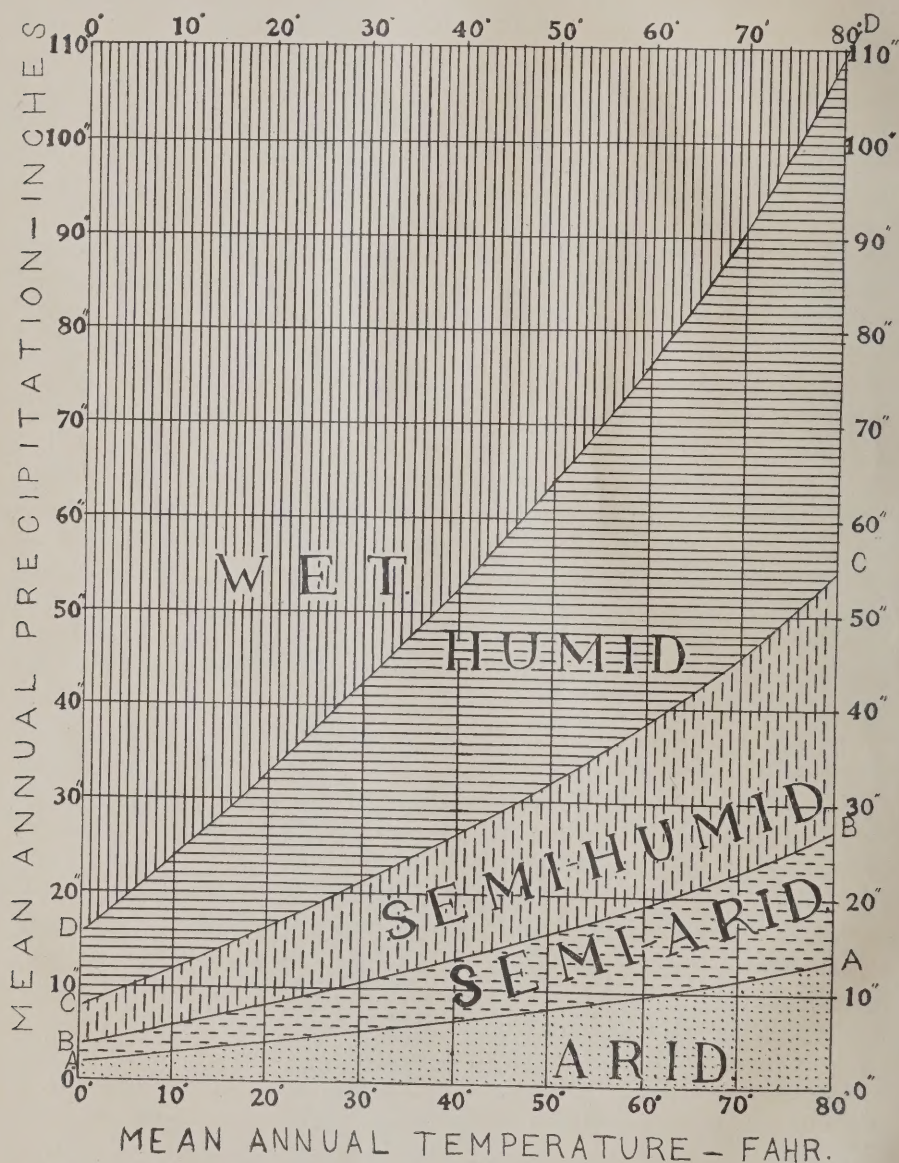


FIG. 2. Chart of moisture, based on precipitation as influenced by temperature.

precipitation and evaporation are in equilibrium, that is, where any additional precipitation would result in stream flow. (Curve *BB*, Fig. 2.) Areas having less than this "critical amount" of precipitation are designated steppes, and those with less than *half* the "critical amount," deserts. (Under Curve *AA*, Fig. 2.)

Köppen used mean annual values of temperature and precipitation; but in the higher latitudes the mean annual temperature has long been regarded as meaningless. In connection with evaporation, however, the temperature of the ground water may be significant, and it should be remembered that the annual temperature curve is rapidly damped and retarded in phase as we descend in the earth. Nevertheless, if there is a distinct wet season, we must consider whether it comes in winter or in summer; more will be evaporated in the latter case, and the net run-off will be less. Köppen proposed to allow for the extra evaporation by deducting 30 per cent of the annual precipitation in regions of summer precipitation, and to make a similar addition in regions having the wet season in winter. He thus in effect reversed the customary ecological procedure of giving more weight to the rainfall of the growing season.

In adapting Köppen's findings for ecological purposes, the writer has omitted this last step, merely indicating separately on the map (Fig. 3) the regions of summer, winter, and "neutral" precipitation, the latter term applying to precipitation uniformly distributed throughout the year.¹ He has renamed the belts, following the more appropriate terminology of Livingston and Shreve; and he has added two more curves (*CC* and *DD*, Fig. 2) by a simple doubling of the precipitation values, thus defining three additional belts. The map (Fig. 3) was prepared on this basis, using the information in Bulletin W of the U. S. Weather Bureau, and various records of the Meteorological Service of Canada. A vegetation map (Fig. 1) is added for comparison; its principal sources are Shreve's two vegetation maps of the United States, and the vegetation map of Canada prepared by the Natural Resources Intelligence Service. Some use has been made of Shantz and Zon's new vegetation map prepared for the Atlas of American Agriculture, and of Craig and Whitford's maps of the Forests of British Columbia published by the Commission of Conservation.

Comparing the two maps, we first observe that the Humid Belt which occupies the eastern part of the continent was originally a great forest area, in which deciduous species are prominent. Its northwestern limit agrees closely with that of white pine and red pine; farther south, its western

¹ In making the classification, May to September inclusive are reckoned as warm months, November to March as cold months. In the summer region three successive warm months have together more than one third of the annual precipitation, and three successive cold months less than one sixth; in the winter region these proportions are reversed.

boundary is that of a number of the common eastern hardwoods. Near the 40th parallel, the forest is extensively invaded by grassland. Gaskill ('06) has stated the reasons for supposing that the invasion is directly due to the



FIG. 3. Moisture belts of Canada and the United States, based on the chart in Fig. 2. The regions of summer, winter and "neutral" or uniform precipitation have been added.

agency of fire. Fire conditions are largely controlled by climatic factors; and it is interesting to note that the incursion of the grasses agrees rather closely with the eastern extension of the summer-rainfall region. The rains of early summer produce a luxuriant crop of grass, which readily carries fire after it has dried. The fires were prevalent in spring and fall; in Wisconsin and Minnesota the greater persistence of the snow cover (shown in Plate 78 of the Atlas of American Agriculture) may have operated to reduce the fire risk and maintain the forest. In the Lake-of-the-Woods region the Archaean formation of the country, with its shallow soils and rock exposures, seems to be unfavorable to grasses, and here the forest holds its own.

West of the Humid Belt we enter a Semi-Humid Belt, which has Summer rainfall east of the Rocky Mountains. In Texas a part of it has neutral distribution of rain, and here the forest tends to enter the belt; elsewhere it is generally grassland, chiefly the tall-grass type of Shantz. Agriculturally, it is celebrated for cereal production; the rain comes when it is needed, and the soils, not being leached at other seasons, are said to maintain their fertility better than those of the east. In Canada this belt is crossed by a forest, in a region which seems to be quite as dry climatically as the grassland; the persistence of the snow cover (as to which very little exact information is obtainable) being the only climatic factor which may be supposed to favor the trees. A part of the region has been described by Connell ('20) and is slightly known to the writer, who is of opinion the presence of the forest may be explained on edaphic grounds. The Archaean area, as has been mentioned, seems to be unfavorable to grasses; and south of it the Saskatchewan River traverses an extensive lowland, where the drainage, for several reasons, is very deficient, and the water-table correspondingly high. This region is an analogue, on a larger scale, of the flood-plain of the Missouri, which likewise carries the forest into the plains. The well-drained uplands of the Pasquia and Porcupine Hills south of the Saskatchewan River are also wooded, but nine-tenths of the area is nearly pure poplar *Populus tremuloides* Michx., a type which is at home everywhere in the Semi-Humid Belt and is spreading rapidly in southern Saskatchewan since fires have been suppressed. The remainder of the upland is wooded with a type in which spruce *Picea canadensis* (Mill.) B. S. P. predominates, and which Connell regards as the climax type of the region, although it does not appear to be extending its limits. The writer suspects that it is confined to the areas where the ground-water stands high.

West of the Semi-Humid Belt and east of the continental divide is a Semi-Arid Belt which is also occupied by grassland, chiefly the short-grass type of Shantz. The land is used chiefly for grazing; but dry-farming has been attempted, with varying success. The corresponding belt to the west of the continental divide presents a different picture; much of it is desert, like the adjoining part of the Arid Belt; elsewhere it is Semi-Desert, or carries groves of juniper and pinón (a type not shown on the vegetation map herewith, but conspicuous on that of Shreve and of Shantz and Zon). The grassland is restricted in area, and for the most part is of Shantz's bunch-grass type. Agriculture without irrigation is seldom attempted (save where the winters are mild enough for growth).

The difference between these belts is due, of course, to the different seasonal distribution of the rainfall. East of the continental divide it comes in summer, at the time the grasses and crops require it; westward it comes in winter and is lost as run-off or sinks in the ground beyond the reach of plant

roots. The xerophytic evergreens seem to be best adapted to reach and utilise this ground-water; they are ready for growth early in spring, and can withstand the droughts of summer.

If Köppen's criterion of balance between rainfall and evaporation had been strictly followed, the Semi-Arid Belt would have been greatly circumscribed in its western portion, and correspondingly extended in the east, where saline lakes occur for some distance beyond its limits as drawn here. On the other hand a formula based on precipitation for the growing season would show the western part to be much drier than the eastern, and would agree better with the distribution of vegetation. It is the writer's opinion, however, that the winter precipitation should not be ignored, since it seems to play a part in supporting the arborescent vegetation.

An arm of the Semi-Humid Belt follows the Rocky Mountains southward, dividing the two Semi-Arid areas; a narrower band follows the east side of the Coast Ranges. In this region the precipitation is of Winter or Neutral distribution; and the typical formation is the Western Pine Forest, composed of yellow pine *Pinus ponderosa scopulorum* Engelm. at the lower elevations and lodgepole pine *Pinus murrayana* "Oreg. Com." above; while the inland form of Douglas fir *Pseudotsuga taxifolia* (Lam.) Britton occupies an intermediate zone, either forming pure stands or mingling with one or other of its neighbors. This forest has a grassy floor, but the grass is thin, and the dead material must accumulate for several years before it will carry fire; under these conditions the forest is able to survive, whereas in the Summer-rainfall region it usually succumbs to fire. The growth of yellow pine in Arizona has been studied intensively by Douglass ('21) in connection with precipitation, and the part played by storage of ground-water is thoroughly discussed. He finds that the annual growth is closely correlated with the annual precipitation, the year for this purpose beginning in the autumn; so that in the ecology of this forest it seems to be erroneous to consider only the rainfall of the growing season.

The same consideration seems to apply in the case of the Cedar-Hemlock Forest which occupies the Humid Belt of the mountains and the Wet Belt of the Pacific Coast. This region is apparently too dry in summer to support deciduous trees, which are confined to the wetter situations such as gravel-bars along the rivers; but it supports one of the most magnificent and luxuriant forests in the world. The leading species are the coast form of the Douglas fir, the Cedar *Thuja plicata* Don., and Hemlock *Tsuga heterophylla* (Raf.) Sargent, the Redwood *Sequoia sempervirens* (Lam.) Endl. (in the south), the Sitka Spruce *Picea sitchensis* (Bong.) Trautv. and Mayer, and the Amabilis Fir *Abies amabilis* (Loud.) Forb. The three last-named species, together with others of less importance, are missing from the Humid Belt of the interior, where the growth is less luxuriant and the appearance of

the forest less extraordinary to eastern eyes. The coast forest, however, is so distinct in its physiognomy that one is tempted to find another name for it; that of Rain Forest suggests itself, but it is used by Schimper ('10) in a different sense. The term of Hygrophytic Forest used by Livingston and Shreve seems to be vetoed by the same authority. The foliage of this forest is adapted to the droughty conditions of summer; but its luxuriant growth (while partly attributable to other factors, such as the length and equable temperatures of the growing season) can hardly be unrelated to the abundant precipitation of winter.

The limits of the forest in northern Canada are doubtless determined by temperature factors, as Merriam ('98) and others have stated, and the same may be true of the Alpine region of the Rocky Mountains. In the Coast ranges, and in all sections where glaciers are formed, the duration of the snow cover becomes the all-important factor, as noted by Taylor ('22) for Mount Rainier. This factor might be expressed as a function of precipitation and temperature; but since snow lies on the surface while rain sinks into the ground, it would be necessary to use much shorter periods of time in the case of snow, and annual mean values would be worthless. A full discussion of the influence of snow cover would require a separate paper; let it suffice to say that the formula here presented does not appear to be applicable in polar and alpine regions. In the tropics the time of year when the wet season occurs is unimportant; the length of the dry season, as Shantz and Marbut ('23) point out, takes its place as the chief "distributional" factor. Within limits, however, it is hoped that the method presented here may prove serviceable for describing the moisture factor in climate, until a more rational system based on direct evaporation measurements is possible. The method may perhaps be refined by taking account of other factors affecting evaporation, e.g., wind and humidity; if so, each step should be tested with reference to its agreement with the vegetation map. The writer believes that he is offering something a little better in this respect than the map of annual precipitation, of which his is a modification.

SUMMARY

1. The distribution of plant formations is largely controlled by climate; particularly by the factors affecting water-supply, namely, precipitation and evaporation.

2. In default of acceptable evaporation records, we may assume that evaporation is proportional to mean temperature; and we may determine the rate at which precipitation must be increased as temperature rises in order to give equivalent degrees of moisture.

3. Using mean annual figures of temperature as abscissae and of precipitation as ordinates, we may now draw curves dividing the world's climates into Moisture Belts, corresponding to thermal zones, and agreeing in their

outlines with the principal types of vegetation (Desert, Grassland, Forest, etc.).

4. Additional factors to be considered are, in arctic climates, the persistence of the snow cover; in temperate climates, the season (summer or winter) of maximum precipitation; in tropical climates, the length of the dry season. These factors may be entered separately on the map.

5. Using five Moisture Belts, we find that the first (Arid) is typically desert, the second (Semi-Arid) semi-desert, the third (Semi-Humid) grassland, the fourth (Humid) forest and the fifth (Wet) a forest of peculiar type, distinguished by remarkable luxuriance of growth.

6. Grasses are favored by summer rainfall; where summer is the wet season they flourish in the Semi-Arid Belt, and tend to invade the Humid Belt, apparently with the assistance of fire.

7. Winter rainfall is of little use to most types of vegetation, but it seems to be utilized by the evergreen conifers. Woodlands and forests composed of these species occur in four of the five Moisture Belts in the Winter-precipitation region, in different degrees of luxuriance.

8. Topographic and edaphic conditions also affect the moisture supply and modify the distribution of vegetation.

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